EXAMINING BUILDING DESIGN DECISIONS UNDER LONG TERM WEATHER VARIABILITY AND MICROCLIMATE EFFECTS:

A case-based exploratory study

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ABSTRACT: Thermal building simulation currently uses Typical Meteorological Year (TMY) data to guide the design decision-making process or for compliance with energy standards. TMY data usually excludes extremes and in many cases are gathered from microclimatic contexts that are not sufficiently representative of the project sites (e.g., airports), adding uncertainty in the analyses. To enable a quantification of uncertainty due to weather by exploring a wide variety of atypical weather conditions, the authors have previously proposed synthetic weather data for building simulation. This is a suite of weather time series, generated from typical weather data that includes heat waves and atypical peak temperatures. In this paper, we used this synthetic weather to examine the effect of considering atypical conditions on design decisions. We also compared the impact of including 'city-modified' weather data on retrofit decisions using urban microclimate simulation.

We found that it may not be viable to pre-select a subset of weather data for all buildings at a given location. Rather, multiple weather data sets may be simulated based on the design strategies and performance criteria of importance. In other words, an extreme condition/year for one building isn't necessarily the same for another. For example, in the case study presented, heat island effect was found to be a likely hindrance to night time cooling. This paper informs the debate on the necessity of expanding the current energy building analyses to a broader consideration of weather variability and more realistic urban microclimate characterization.

Keywords: overheating, stochastic weather inputs, design decision making, building simulation.

INTRODUCTION

In recent decades building simulation tools have come to be used extensively for building design decision making, as well as demonstrating compliance with energy codes in many countries. However, the measurement of performance using building simulation is affected by many uncertainties, weather being one of them (Tian & de Wilde, 2011).

In the past, to overcome computational limitations, simplified representations of the weather were created such as the ASHRAE definition of the design-day or the Typical Meteorological Year (TMY, Wilcox & Marion, 2008). A handful of similar standardized procedures have been adopted across the world for creating these representative years irrespective of climate and building type. It is perfectly reasonable to hold that standardisation of weather inputs lends itself to comparable energy-driven analyses, the logic being that using standardised inputs leaves only the building designs as a source of differences. However, the authors and others have argued elsewhere (Chinazzo, Rastogi, & Andersen, 2015; Hong, Chang, & Lin, 2013; Rastogi & Andersen, 2015) that, given the complex interaction of buildings with their climate, these typical years do not guarantee comparable performance in all situations. Simply put, a single standard input giving a single output creates an illusory precision that will show differences without statistical rigour.

For example, Sun et al. (Sun, Gu, Wu, & Augenbroe, 2014) found that carrying out dynamic simulation over 30 years' worth (1982-2013) of actual meteorological data did not result in peak cooling demand as calculated per the ASHRAE design-day for their reference case. Peak cooling demand was found to be 19.6% less than the ASHRAE design day. Porritt et al. (Porritt, Cropper, Shao, & Goodier, 2012) compared effectiveness of various building retrofit measures and user control measures under an atypical weather scenario (European heat wave of 2003) and found that design choices that benefit both typical and atypical scenarios exist. Different weather data sets thus come with unique abilities to assist design decision making. However, it is not always evident which data set would suit the design needs the best and would be most beneficial with the decision making process.

Uncertainties in weather make selection of data for design particularly challenging. Uncertainties can be found in the historical data due to unreliable measurements, local land use, or change in instrumentation, among others. Future year projections are affected by modelling uncertainties. Leaving aside uncertainties in measurement, which show up in a typical year file, we address the 'temporal uncertainty' that would affect predictions of future energy use by using four different types of weather data sets, described in the subsection on weather data below.

This discussion gains further importance for buildings where active space conditioning systems are not included, as is the case for large parts of Europe, Asia, and Africa. This reduces the ability of the occupants to remain comfortable under to extreme conditions, since the thermal comfort is now far more strongly linked to the outdoor conditions. In situations where active systems do exist modelling extreme situations would be of great interest to utilities who can expect significant spikes in electricity usage as these systems are switched on.

The intent of this study is to enhance the understanding of the analytical capabilities offered by different weather data sets using an example design problem and some proposed design strategies.

METHODOLOGY

A case study approach was taken to discuss the role and impact of the weather data type used in the design process in its real-life context. The design problem formulated to do this, was generated with the view that local codes and guidelines tend to provide greater design support to designers regarding the dominant weather condition. With limited design guidance regarding the non-dominant weather condition and a single weather scenario being used, the likelihood of an inadequate design response is higher. A design problem was fabricated in a climate that is heating dominated (Geneva, Switzerland). To ensure that the discussion does not become too specific to the subject building type that we happened to choose, two other variants of the same problem were also selected.

All available types of the hourly weather data were gathered in order to simulate the annual performance of the case subjects.

To analyse the variation in building response to the weather data, the buildings with different orientation, size and degree of exposure were selected. However, the proposed design interventions and operational characteristics, were kept the same for each case. The effectiveness of the design decisions could then be compared for different buildings under multiple weather scenarios. The detailed annual thermal simulations were carried out using EnergyPlus software. Microclimatic assessment, which involves far greater computation time compared to the building thermal simulations, was limited to some selected representative days to assess possible implications for the design strategies. Weather data of varying duration and granularity was thus used in this study.

Weather Data

There are four kinds of hourly weather data used in our analyses: typical, recorded, synthetic-plain (SYN), and synthetic-rcp (RCP8.5).

The typical years include, one from the IWEC series (ASHRAE, 2001), and two from the Meteonorm software. Recorded data from 1981 to 2013 were downloaded from the Swiss meteorological service (MeteoSwiss, 2014).

The two sets of synthetic weather data have been developed by the authors, and described in previous publications (Rastogi & Andersen, 2015). The SYN series do not explicitly include climate change forecasts while the RCP8.5 series do. The IPCC's climate change forecasts are summarised in Summary Report AR5, 2014 and were downloaded as predictions of daily mean values (temperature, solar radiation, and humidity) for the period 2016-2100 from the CORDEX website (2015). The Representative Concentration Pathway (RCP) used in this study assumes a radiative forcing of 8.5 W/m^2 (RCP8.5), which the IPCC report describes as a "high RCP" scenario, i.e., with very high GHG emissions.

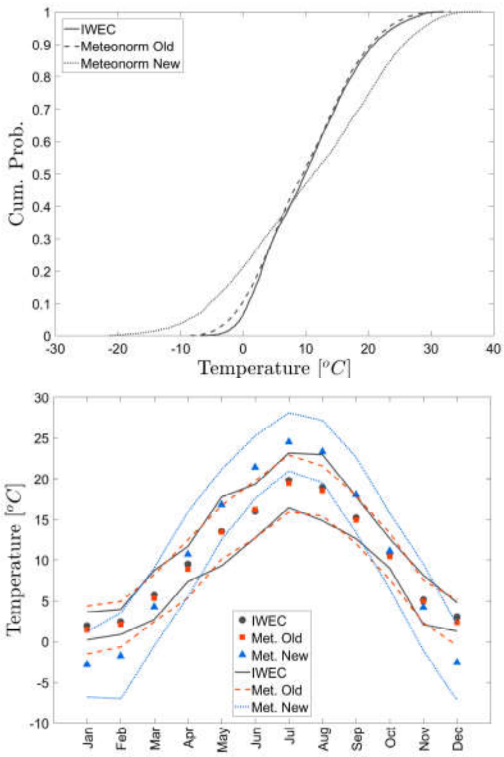

Figure 1 [top] CDFs of Dry Bulb Temperature (DBT) for the three 'typical weather' files used in this paper; [bottom] symbols show monthly median values and lines show 75th and 25th percentiles for the typical files for Geneva. The new Meteonorm data, based on records from 2000-2009, shows more extreme temperature values than the old Meteonorm file from 1961-1990.

The two synthetic data sets are used in exactly the same manner as the typical weather files: hourly simulations over a whole year. However, the "year" of a synthetic data file is not to be taken literally. The plain files are meant to be equi-probable for every year in the future, so cannot be separated into the 'immediate future' or the 'far future'. They assume a stable climate, i.e., that the overall statistics of the climate in question will not change significantly in this century. The RCP8.5 files, on the other hand, do carry tags indicating a specific future year and assume a slowly-changing annual mean temperature (1.5°C for Geneva). Following the original IPCC data, the files are arranged in an arbitrary number of 'strings' of 85 years each (2016-2100). Each year or string is a 'variant', i.e., it has some probability of occurring in the future. Each string does not, however, represent a single pathway for the evolution of the climate. A possible rule of thumb is to treat all years in a decade, and all variants of those years, as equally probable for the decade in question. There is no 'correct' number of variants to be generated and simulated. It depends on the computing power available and whether a feature of interest has been generated or not (e.g., a heat wave). For this paper, we were able to simulate four such strings. The consequences of this relatively small sample (compared to the plain synthetic files) are discussed in the results section.

Case Study Buildings and Thermal Simulations

The impact of synthetic weather data on design decision making is demonstrated in this paper using three existing mid-rise buildings in the dense urban centre of Geneva (Figure 2 and Figure 2). The premise of the design problem is that these buildings were built before energy codes became effective, and need to be renovated to meet the new Swiss regulations (SIA 380/1, published by the Swiss Society of Engineers and Architects in 2009). Given that the applicable energy code in this case is directed towards a heating dominated scenario, we evaluate the occurrence of overheating, post renovation, in each building using various types of weather data. None of the buildings have active cooling systems and the design performance is evaluated based on heating energy use (not included in this paper due to space limitations) and overheating hours.

Building simulations were performed using Energy Plus building simulation software v8.3. DesignBuilder v4.5.08 was used to develop the initial models, which were then exported as EnergyPlus input data files (IDF). The minimum permissible insulation levels under the current energy standard (SIA 380/1) were used (refer to Table 1 for inputs). The standard also states that a higher insulation value is desirable. Current regulations also limits the number of overheating hours to under 100 in a typical year. We used this as a benchmark to make additional changes and assumptions (e.g. glare-based blind operation, window opening area percentage). In all cases the decisions were made with simulations using the IWEC weather file. The decision not to use the higher (target) values suggested by SIA was guided by the need to reduce overheating below 100 hours, which was not possible without drastic changes to windows and shading devices.

Any time an occupant is present, and the indoor temperature exceeds 26.5 °C, all windows in the concerned zone are opened for natural ventilation. The

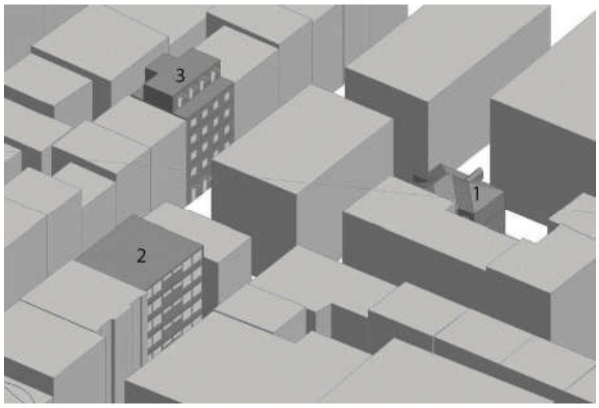

Figure 2: Subject buildings with neighbouring buildings as modelled in Design Builder

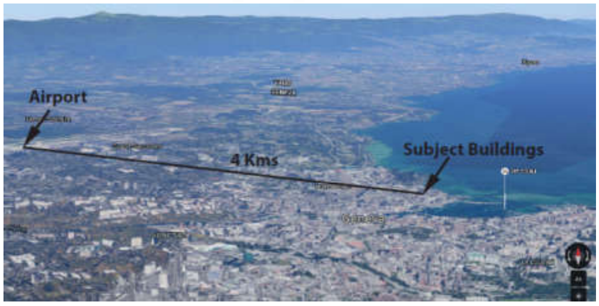

Figure 2: Subject buildings shown their immediate neighbourhood. Image Credit:www.google.ch/maps

Table 1: Key thermal model inputs

Building Parameter	Input Value	Other possible Inputs
Exterior wall U value [W/m^2-K]	0.20 (minimum limit value)	0.09 (suggested target value)
Exterior Roof U value [W/m^2-K]	0.20 (minimum limit value)	0.09 (suggested target value)
Exterior Window U value [W/m^2-K]	1.3 (minimum limit value)	0.9 (suggested target value)
WWR	18-28%	
Infiltration	0.3 ACH in heating mode	
Internal Lighting	3.4 W/m^2	
Occupant density	33 m^2/person	

external shading devices are controlled based on glare. Night time ventilation is also included as a passive cooling strategy.

Given that this study focusses on capturing the likelihood of overheating, an optimistic operation regime (from the point of overheating) was modelled and tested against different weather data sets. However these assumptions would be difficult to sustain if, for example, the buildings being studied were used by older residents, whose ability to adapt should not be taken for granted.

The simulation results are expressed in terms of annual overheating hours calculated based on the current applicable indoor thermal comfort norms in Switzerland for buildings that have no active cooling systems (SIA 180, 2014). The interior zone operative temperature and a 48-hr moving average of the outdoor dry bulb temperature were recorded hourly from each simulation run. The unmet hours or overheating hours are calculated based on the upper limit of indoor operative temperature, which is calculated as follows for each hour:

$$T_{op} = 0.33 * \theta_{ma} + 21.8 ,$$

where,
T_{op} = Permissible Indoor Operative temperature [ºC]
θ_{mn}= 48-hour moving average, outdoor dry bulb temperature [ºC].

Microclimate assessment

In addition to the previous study, the influence of urban heat island (UHI) effect on temperature variations has been investigated. To this end, the software ENVI-met has been used to simulate the interactions between the local environment (urban geometry and surface types) and the urban microclimate. An area of 200x300m encompassing the buildings under consideration was modelled according to a 3d-nesting grid of 60x40 (grid size= 5m).

Five receptors were set in front of the façade of the buildings in order to observe:

- The average and highest difference between the temperature of the weather file (T_{wf}) used as input and the mean urban temperature (T_u). The latter was calculated as the average of the five receptors values resulting from ENVI-met simulations;

- The temperature variations between the receptors, as a result of the variability of the surface thermal properties in combination with the three-dimensional geometry of the area.

Given the considerable time for computation required by the software, a limited number of daily simulations were run categorized by: weather file type (TMY, SYN, RCP8.5), sky condition (sunny, partially cloudy, cloudy) and air temperature – average cold (C), average mild (M), average warm (W), warmest (Ws), heat peak (P). The sky conditions were categorised based on the percentile groups of direct normal irradiation (DNI) data from each type of weather data. For example the hours with the top 25% percentile DNI were categorized as sunny. The weather types, cold, mild, warm, etc. were categorised based on percentiles groups of daily mean dry bulb temperature. All these day types were to create climate boundary conditions of the microclimate model.

RESULTS AND DISCUSSION

The results from the simulations are presented in Figure 3. The Cumulative Distribution Functions (CDF) of overheating hours provide a handy way of checking the fitness of building retrofit options against a range of possible future years. Each value of the sum of overheating hours (e.g. 50 hours) occurs a certain number of times in a given set of simulations (i.e., simulations using a specific weather data set). So, for example, the sum of overheating hours is less than 50 for 100% of the RCP8.5 simulations. The same is true for the recorded data. In the synthetic plain data set, however, the sum of overheating hours exceeds 50 in 8% of the notional years.

All the cases under consideration were renovated to comply with Swiss regulations regarding overheating by checking against the IWEC weather file only, and the changes turned out to be robust to a whole suite of possible future weather data. Geneva, is a central European city with a climate classification that is shared with large parts of Europe (e.g. France, northern Spain) and a similar verifications could be performed of design projects.

However on further examination of building 2, we find there is a substantial difference between the overheating hours calculated with the IWEC TMY weather file compared to other weather data sets. For example the new Meteonorm TMY data results in 64 unmet hours per year while the IWEC TMY data results in zero. If the analysis of this building was based only on the IWEC TMY weather data, higher insulation levels could have been considered as a possible design option to further save on heating energy. However the same would not be advisable based on the new Meteonorm TMY file where adding more insulation could perhaps lead to unmet hours exceeding the permissible limit of 100 hours per year. The newest Meteonorm file, based only on the decade of the 2000s, is more 'extreme' than the other typical files, which are based on data from 1961-1990 (Figure 1). If the climate has indeed become a little warmer, then the higher summer averages make sense. In any case, basing a statistical procedure on a smaller sample makes it more vulnerable to extremes. That is not to say, however, that the 'new' Meteonorm file is not representative – it is, for the 2000s. This comparison thus leaves us with the dilemma whether the last decade in this case is an anomaly or the new expected future trend.

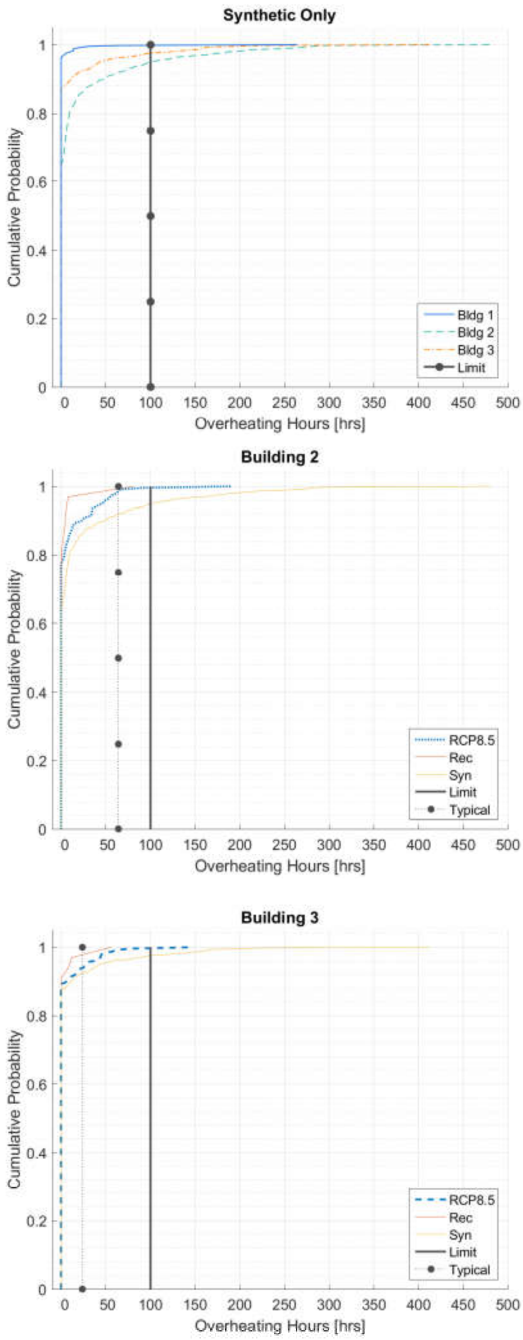

Figure 3: CDF of overheating hours for all buildings, using only the synthetic weather files [top]; building 2 [middle]; and building 3 [bottom]. Within the subplots, each CDF line represents the results from a weather data set. The 'limit' represents the 100-hour limit of overheating allowed by Swiss law. Of the 'typical' files, only the new Meteonorm file showed overheating, so the others are not plotted. Building 1 is also not given an individual plot since it almost never shows overheating.

The RCP weather data could also be of assistance here as a basis for rejecting or selecting the TMY files. For example the unmet hours predicted per the new Meteonorm file in case of building 2 exceed those predicted by the RCP files for 99% of the years. This appears to be unreasonable. Hence a TMY based on a longer record would be advisable in this case.

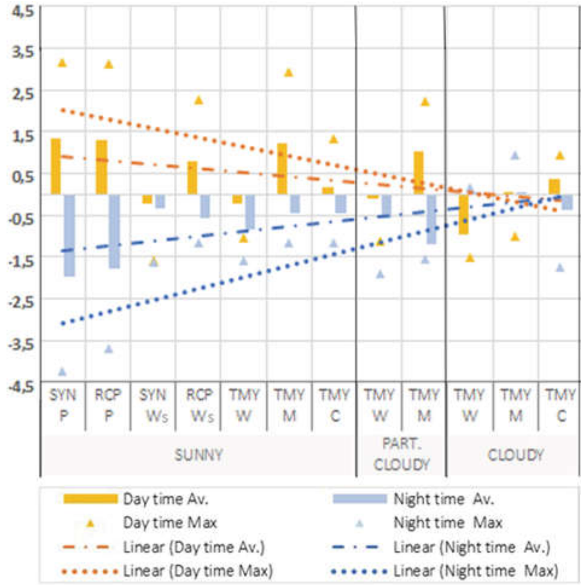

Figure 4: Average and max ΔT between weather files and ENVI-met data (ΔT = Twf – Tu)

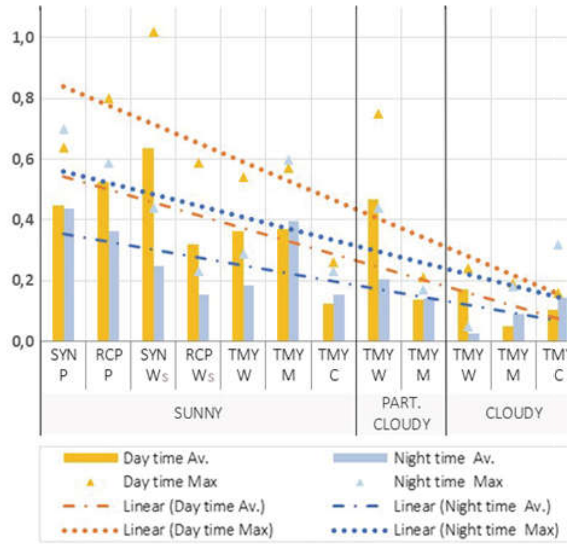

Figure 5: Average and max ΔT between receptors

Results from the microclimatic assessment simulations show that the higher the solar radiation (clear sky) and the air temperature (warm and mild days), the more intense UHI effects are (Figure 5). The increase of temperature attributable to the UHI effect is the largest during night-time and particularly when heat waves occur during the day (SYN P and RCP P), with Tu rising up to 4.25°C.

Compared to the weather file data, the simulated wind speed is significantly lower, with values decreasing on average by 1/2 to $1/7^{th}$. Existing literature (Morris et al. 2001, Yow 2007) shows that the drop in wind speeds further contributes to the heat island intensity at night. Figure 4 also shows that UHI tends to disappear by day and the urban area can even be cooler. These findings are consistent with several UHI studies (Oke, 1982, Arnfield, 2003). In addition, Figure 5 show that temperature variation between receptors is generally more significant during daytimes with cloudless sky (ΔT up to 1°C), while it diminishes as the weather gets cooler and overcast.

CONCLUSIONS

With a simple case study, we were able to see some of the ambiguities in the commonly used weather data. While these ambiguities may not be common to all locations, we find that even at an established weather station such as Geneva, long historical data sets may not provide a clear picture. The 'plain' synthetic series was found to provide a fuller spectrum of weather-year possibilities with the distribution of data centred on the typical scenario. This property of the synthetic data can be used to overcome limitations of recorded data such as in the case study discussed in this paper, where the recent weather history seems very different from the medium term weather history, or in cases where atypical weather events of interest are not seen in the available recorded weather data sets for a given location.

In this study we are using aggregate metrics, which means that some information is lost in the analyses. For example, a long somewhat-warm week will produce many more overheating hours than a spell of extremely warm temperatures lasting only a day. In other words, overheating hours do not give any indication of the 'distance' from some comfort threshold. This could be addressed in future work as this would further help in illuminating the true nature of the weather data.

The UHI effects were found to be more pronounced on warm sunny days. The increased night time temperatures, following such days provide motivation to attempt assimilation of UHI effects into annual weather data for the study of annual frequency of such occurrences and for comprehensive design performance analysis.

While findings in this paper refer to a specific case study, they contribute to inform the debate on the necessity of expanding the current energy building analyses to a broader consideration of weather variability and more realistic urban microclimate characterization.

ACKNOWLEDGEMENTS

This work was supported by the Euro Tech intiative and SECURE (Synergistic Energy and Comfort through Urban Resource Effectiveness) project funded by the CCEM (Competence Centre for Energy and Mobility)

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